Calculation Of Crankshaft Twist Angle Using Multibody Simulation And Finite Element Method

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Topics of the study

- Calculation of the crankshaft twist angle thanks to a finite element approach
- Dynamic simulations of a twin–cylinder boxer engine using rigid and flexible parts models
- Simulations using super element technique
- Comparison of the results obtained with this approach to the ones obtained with finite element analysis

Background

- Valve and fuel injection timing are based on crankshaft angular position for internal combustion engine (ICE)
- But crankshaft deformations are not considered
- Large crankshaft twist angle can lead to bad injection timing or to contact between pistons and valves
  - Bad combustion process => excessive fuel consumption, pollution
  - Risk of engine breakdown

Objectives

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- Definition of the crankshaft twist angle and specification of how to measure it
- Calculation of the crankshaft twist angle for a complete engine cycle in steady state and for several rotation speeds
- Crankshaft model reduction to decrease calculation time (in order to study engine transient operating conditions)

Torsion

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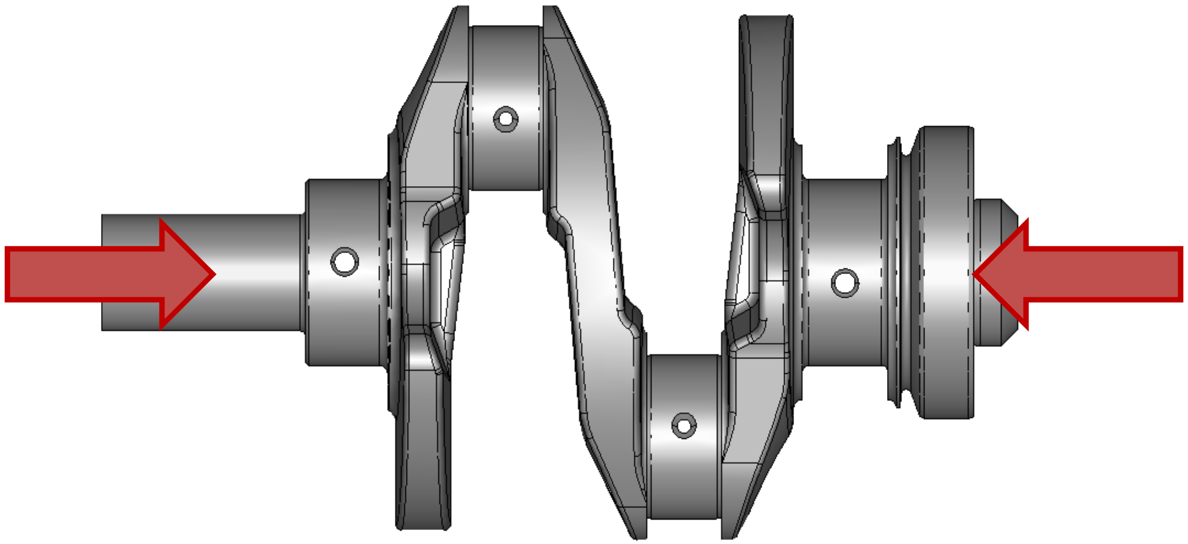
- Several definitions depending on the engine configuration and on the objectives of the calculation
  - Here, we studied the torsion of the whole crank

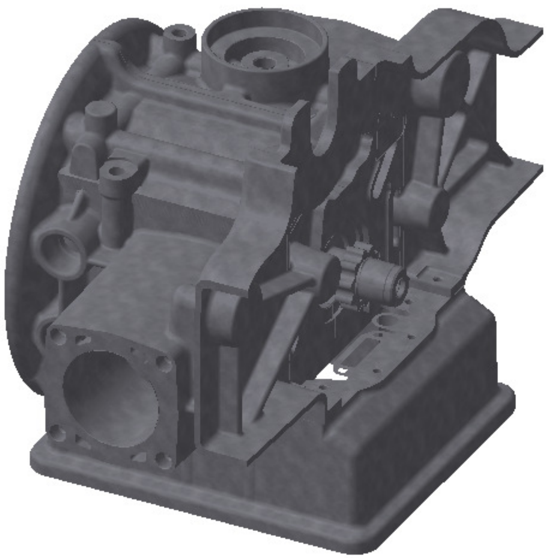


Simulation software

- Engine simulations are performed using finite element approach with SamcefField MECANO software developed by LMS Samtech (Siemens group) and historically by the university of Liège

Twin-cylinder boxer engine

- Twin-cylinder boxer engine:
  - Flat engine with opposed cylinders and pistons moving in phase (reaching their top dead center simultaneously)
  - Naturally balanced, do not require balance shafts
  - Low center of gravity



Engine model

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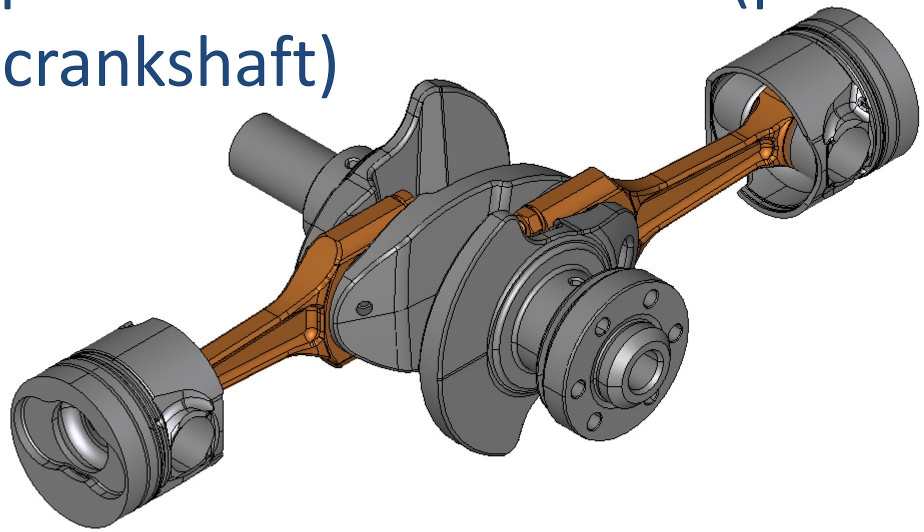
- Engine model is made with real geometry coming from the CAD model of a prototype engine (provided by Breuer Technical Development)
- Engine model is simplified, only the most significant mobile parts are kept for the simulations (pistons, connecting rods and crankshaft)

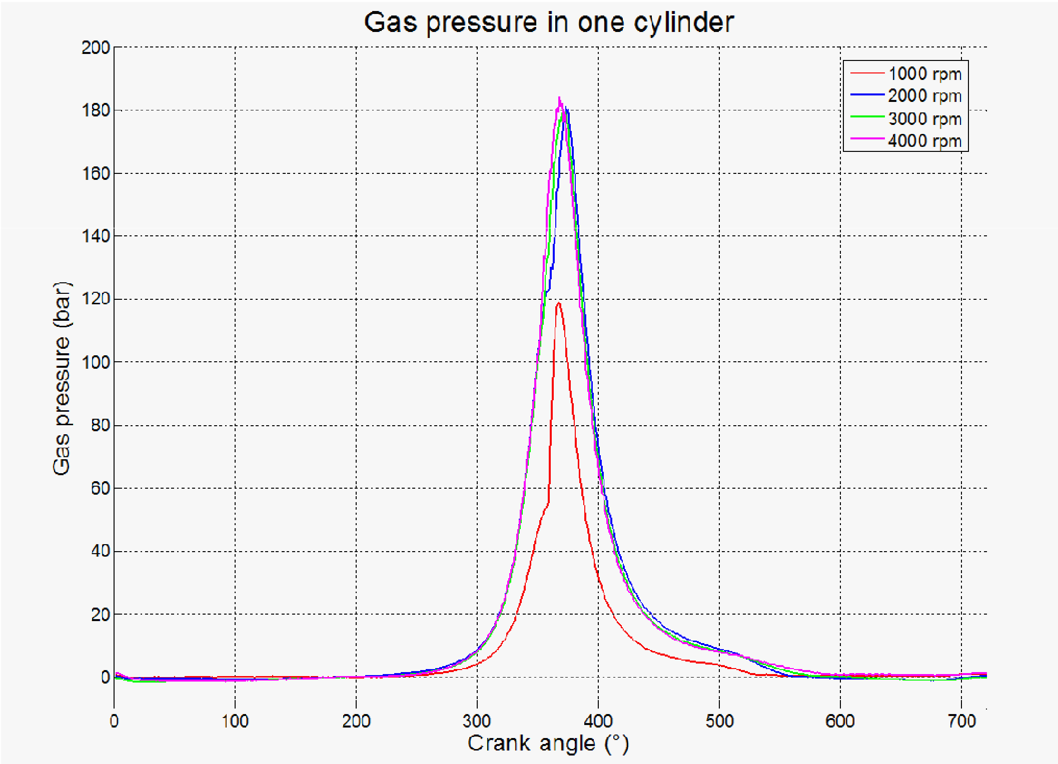


Engine model

- Pistons and connecting rods are considered as rigid bodies and the crankshaft is meshed with flexible finite elements thanks to the finite element approach of MECANO
- Crankshaft strains and stresses are calculated for the complete engine cycle in a dynamic simulation (with imposed crankshaft rotation speed including or not the gas pressure effect)

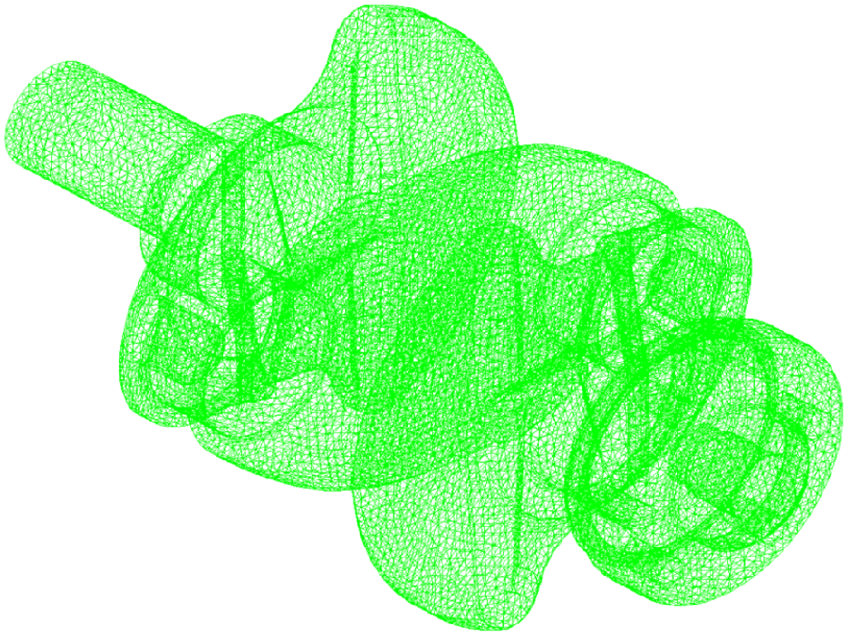
Gas pressure model

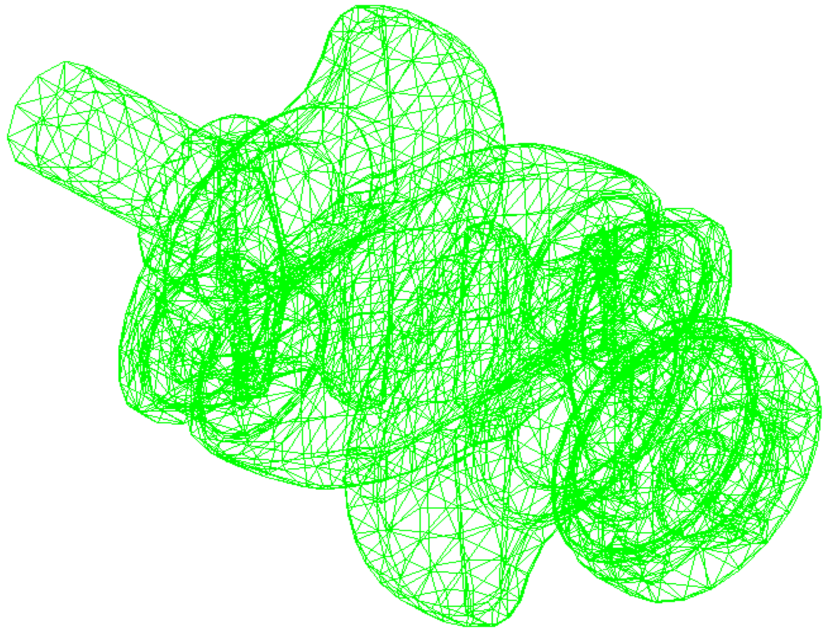
- Gas pressure inside a cylinder (experimental data)



Finite element model

- Classical finite element approach:
  - 283700 first order tetrahedral elements of 3 mm average size (good compromise for stresses analysis)
  - 21838 second order tetrahedral elements of 11 mm average size





Finite element model

- Multibody approach:
  - Rigid hinge model of bearing surfaces is used
  - Chung-Hulbert time integration algorithm
- Twist angle determination
  - Some particular nodes are connected to each extremities of the crankshaft and their rotation angles are measured
  - Difference between the two rotation angles = torsion
- Simulations (2 engine cycles) take a lot of time (50 hours for 280000 elements or 2.2 hours for 21000 elements) and computing resources

Twist angle at 2000 rpm

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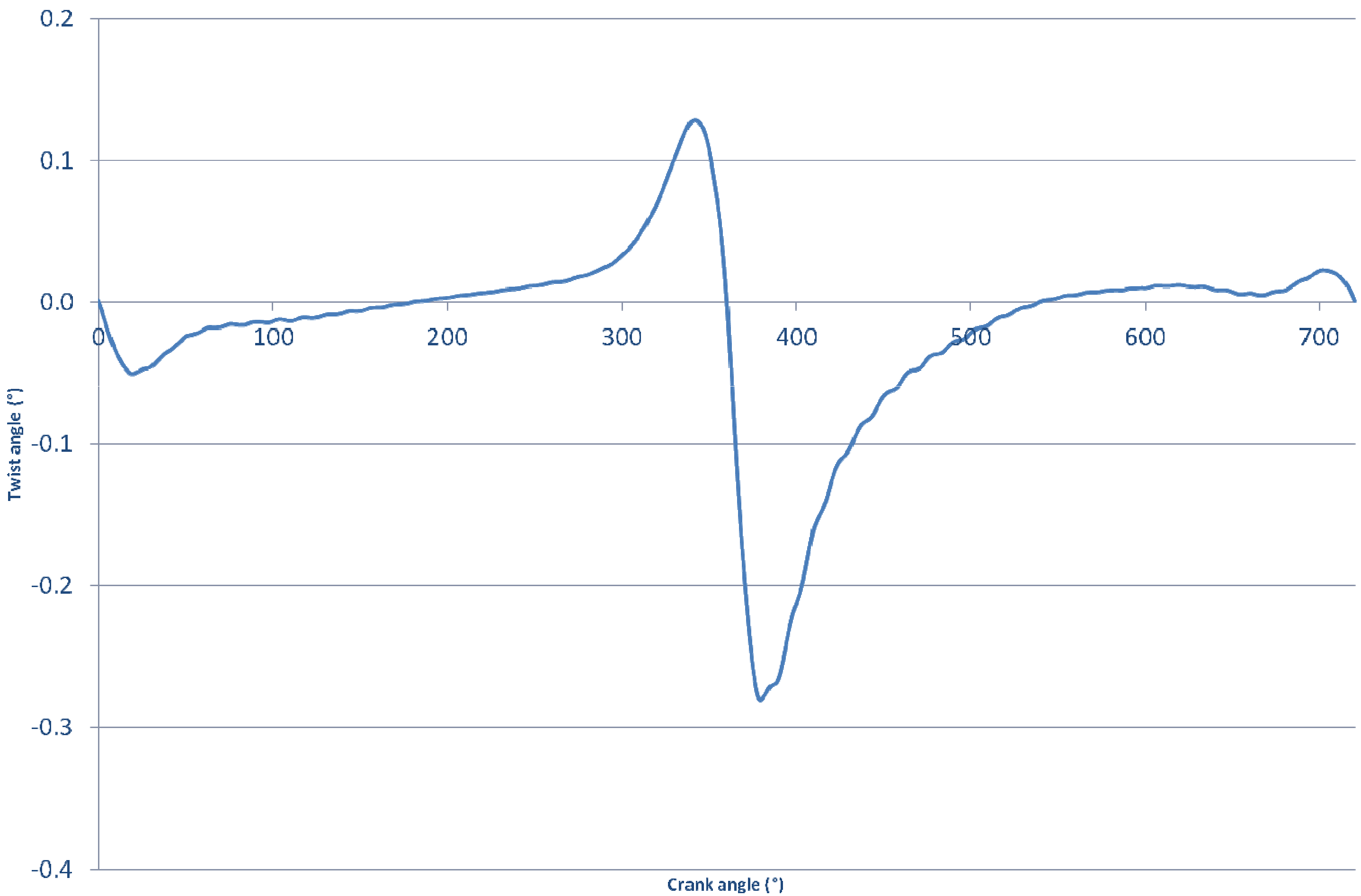
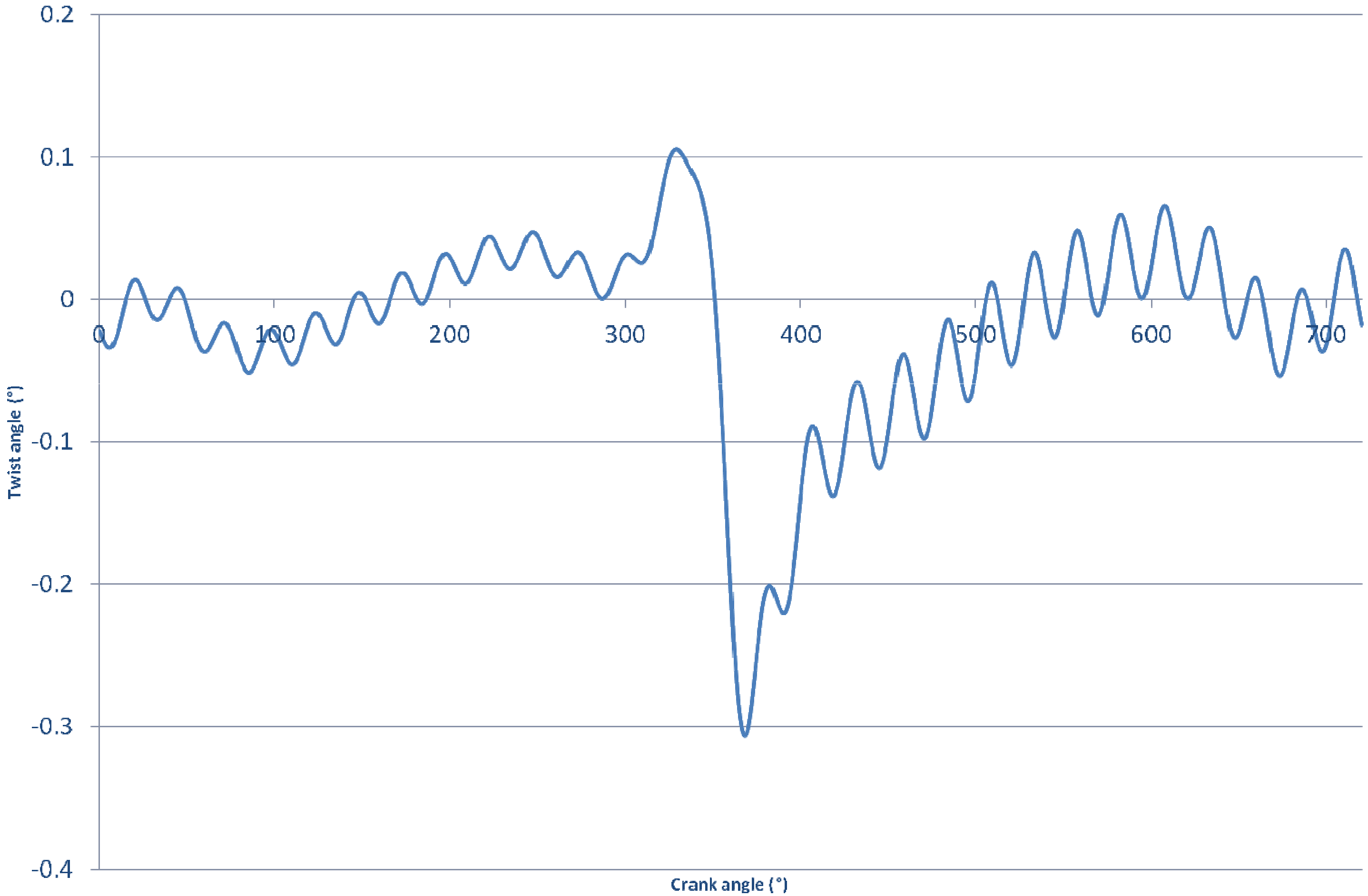


Twist angle at 4000 rpm



Super element approach

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- Substructure technique used to reduce the size of a problem
- Nonlinearities are assumed concentrate in the joints
  - Motion (especially rotation) and the deformation of a body can be decoupled
  - Deformations of the body remain small and linear in a local frame attached to the body
  - The body is represented by a super element containing the internal modal information and linked to other bodies allowing to keep a relatively simple global dynamic model

Super element approach

- Simulations using super element technique require 3 steps:
- Creation step:
  - Super element of the crankshaft is created by deleting some DOF and keeping only the boundary DOF and a reduced set of eigenmodes (Craig-Bampton condensation method)
  - The mass matrix and the stiffness matrix of the crankshaft are reduced and assembled with the rest of the system like an usual finite element

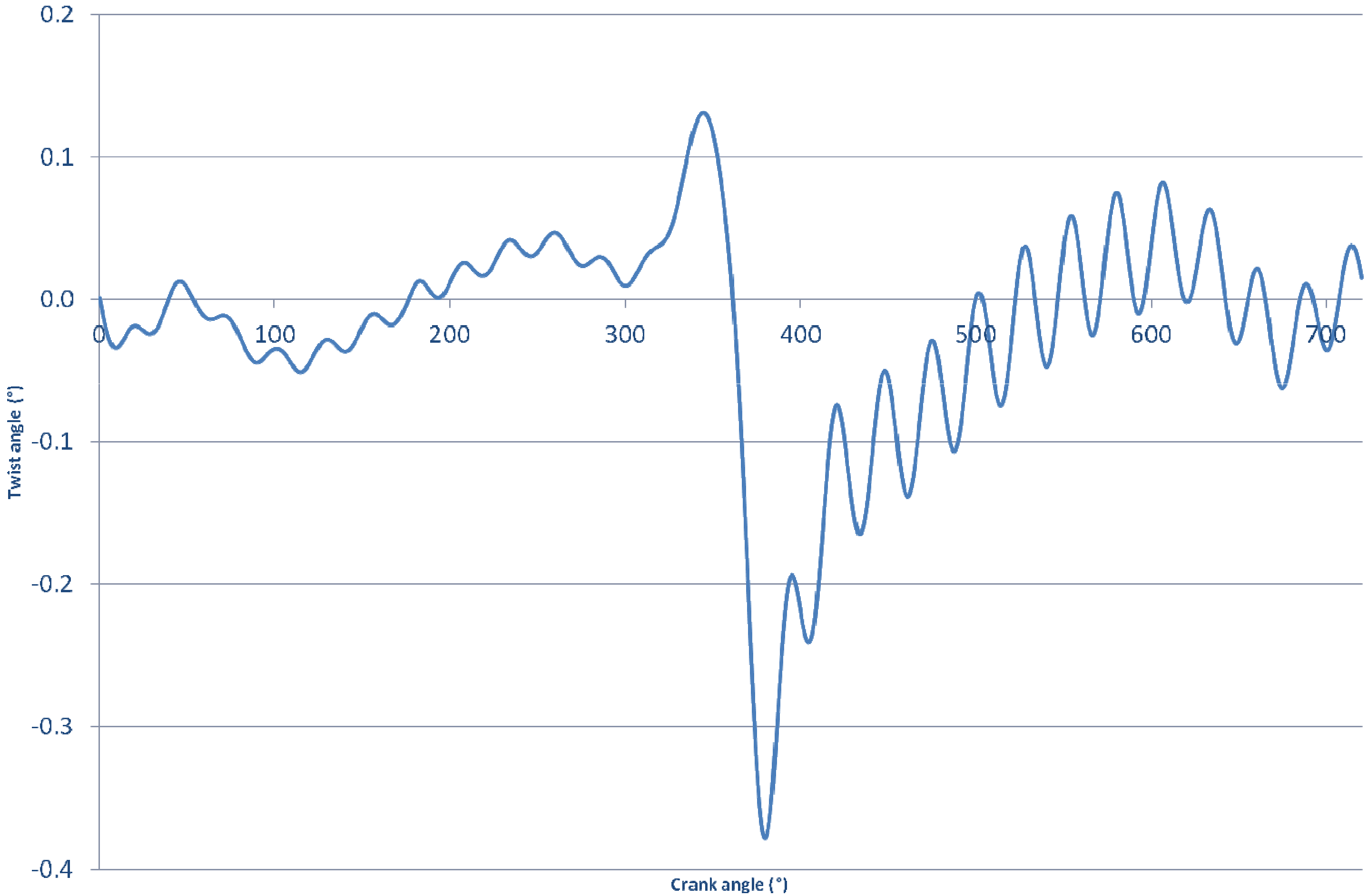
Super element approach

- Calculation step:
  - Super element is assembled in the global system
  - A dynamic multibody analysis of the global system (the engine in this case) is performed
  - Results from the global simulation are obtained (position, speed, acceleration, force, moment, twist angle…)
- Results recovery step:
  - Some specific results of the crankshaft, for instance strains and stresses, can be recovered by a dynamic analysis of the super element

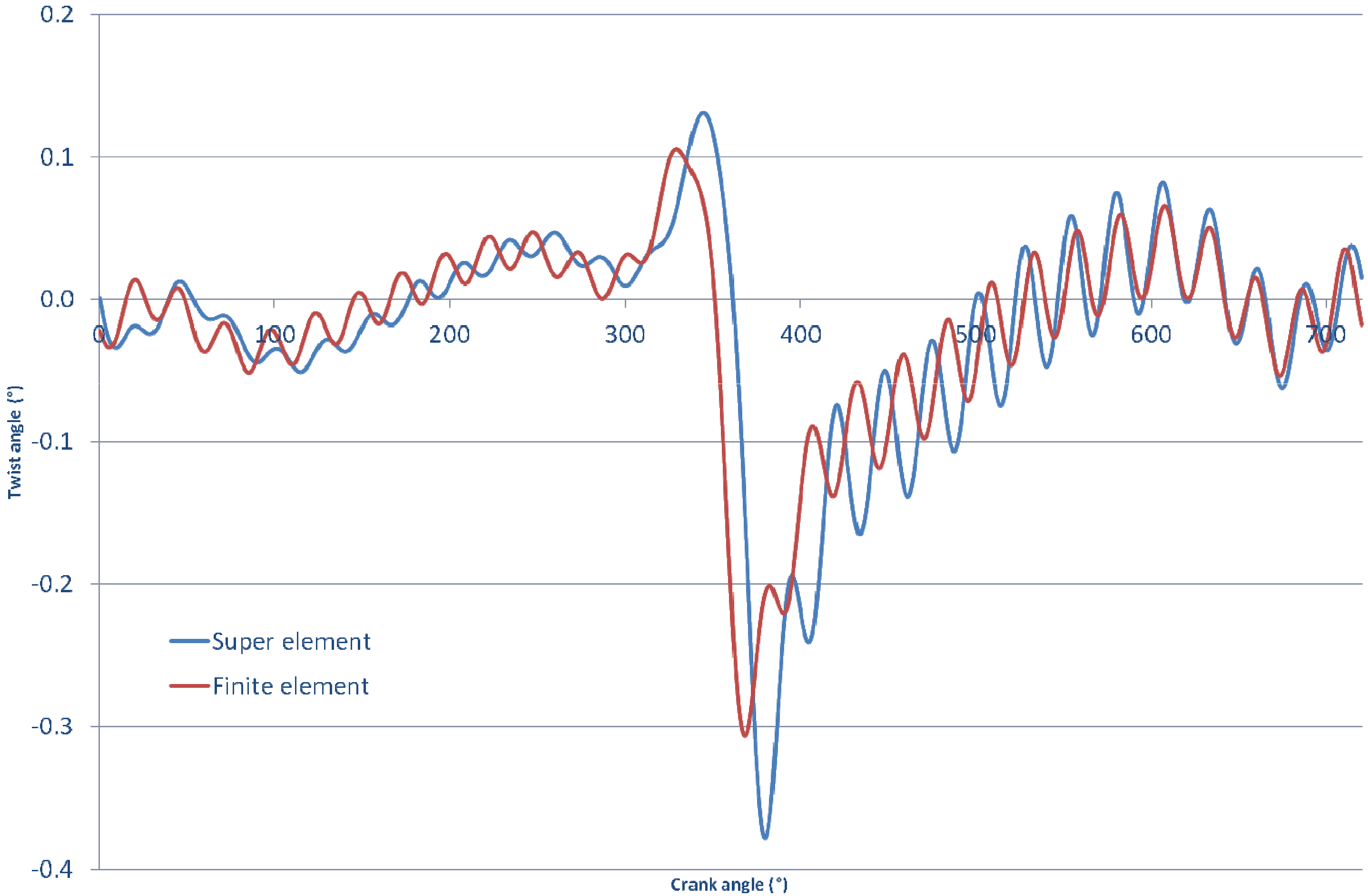
Super element model

- Dynamic simulation of the engine using a super element model of the crankshaft
  - Super element is created with the crankshaft meshed with 22000 second order tetrahedral elements of 11 mm average size and keeping 5 eigenfrequencies
  - Rigid hinge model of bearing surfaces is used
  - Chung-Hulbert time integration algorithm
  - Engine speed = 4000 rpm

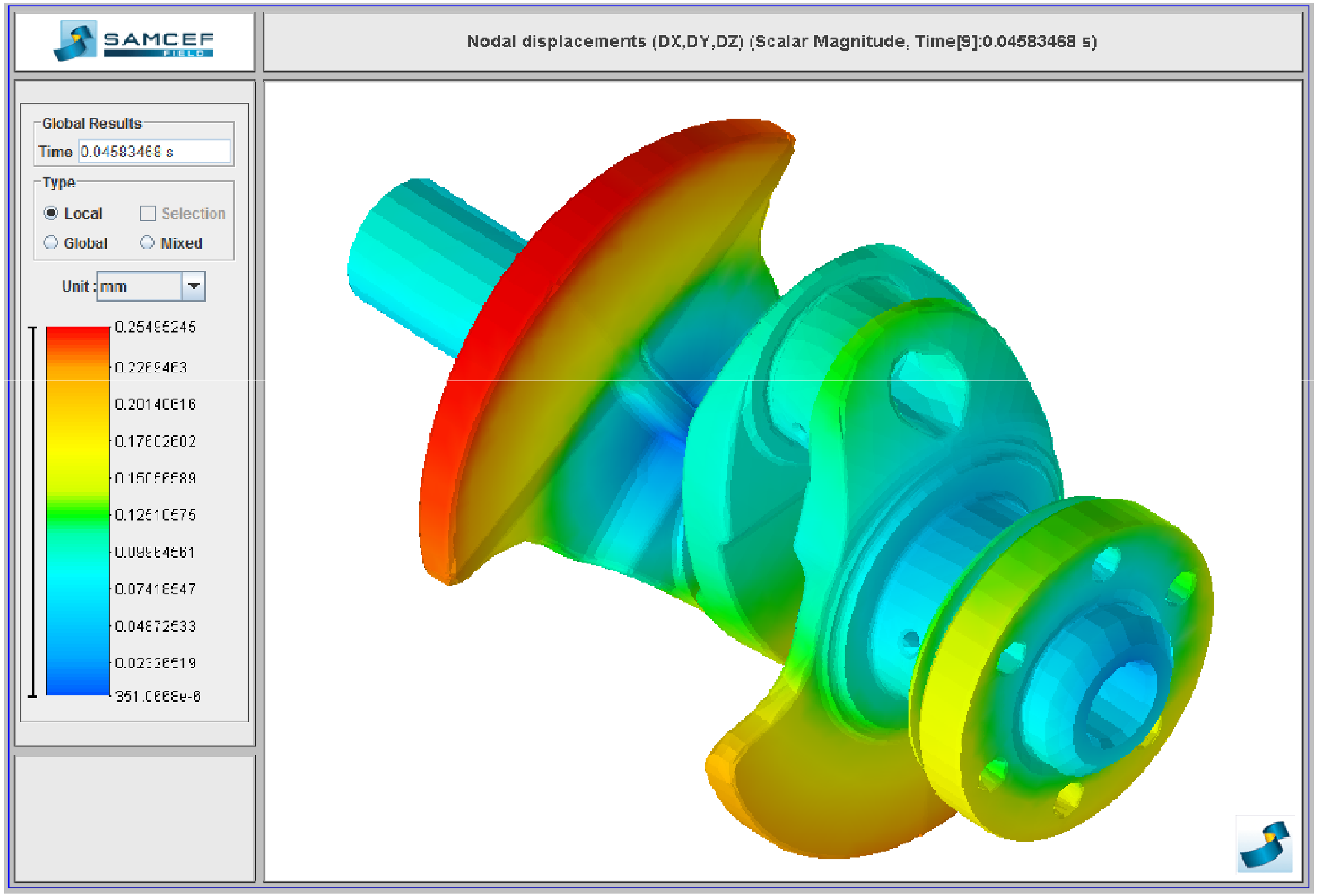
Twist angle with super element



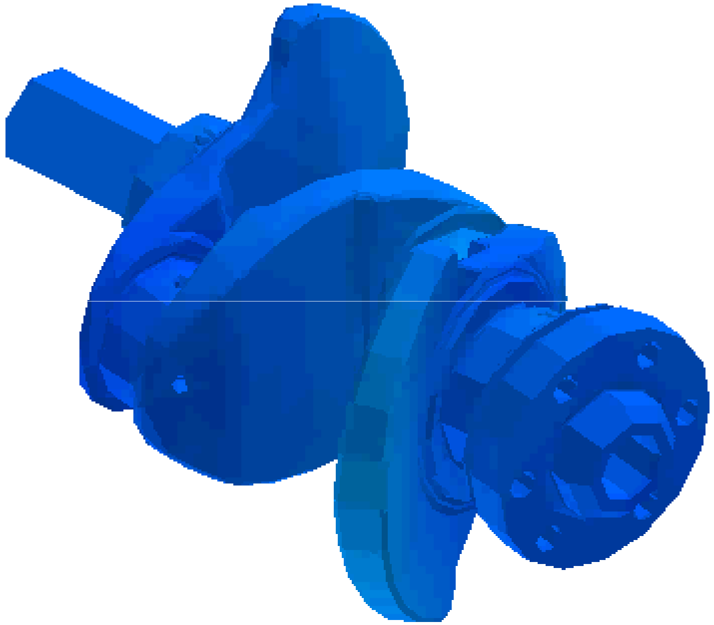
Comparison of twist angles



Crankshaft deformations



Crankshaft deformations



Computation times

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- CPU times (on a quad-core 2.8 GHz computer) for a simulation of two engine cycles at 4000 rpm (0.06 s):
  – Refine finite element model : 50 hours
  – Finite element model : 2.2 hours
  – Super element model : 10 secondes + creation of the super element

Conclusions

- Multibody simulations offer interesting prospects for engine design:
  - Determinations of forces and moments acting on each parts of the mechanism
  - Flexible body dynamic simulation
    - Allows strain and stress analysis for each time steps of the simulation
    - Especially, to calculate the torsion of the crankshaft
    - But require lots of computing resources and time => need for **reduced order models**

Conclusions

- Super element method allows to:
  - Perform quicker simulations
  - Isolate the displacement coming from the deformation and from the rotation

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Thank you for your attention